

# TEST CASE DOCUMENTATION AND TESTING RESULTS

LSTC-QA-LS-DYNA-AWG-ERIF-7-10

TEST CASE ID AWG-ERIF-7

Ballistic Impact on Composite Plate

Tested with LS-DYNA® R9 Revision 118235

Wednesday 12<sup>th</sup> July, 2017

**Warranty Disclaimer:**

The test case(s) described herein are for illustrative purposes only. LSTC does not warrant that a user of these or other LS-DYNA features will experience the same or similar results or that a feature will meet the user's particular requirements or operate error free. FURTHERMORE, THERE ARE NO WARRANTIES, EITHER EXPRESS OR IMPLIED, ORAL OR WRITTEN, WITH RESPECT TO THE DOCUMENTATION AND SOFTWARE DESCRIBED HEREIN INCLUDING, BUT NOT LIMITED TO ANY IMPLIED WARRANTIES (i) OF MERCHANTABILITY, OR (ii) FITNESS FOR A PARTICULAR PURPOSES, OR (iii) ARISING FROM COURSE OF PERFORMANCE OR DEALING, OR FROM USAGE OF TRADE OR. THE REMEDIES SET FORTH HEREIN ARE EXCLUSIVE AND IN LIEU OF ALL OTHER REMEDIES FOR BREACH OF WARRANTY.

| Document Information |                                                     |
|----------------------|-----------------------------------------------------|
| Confidentiality      | <b>external use</b>                                 |
| Document Identifier  | LSTC-QA-LS-DYNA-AWG-ERIF-7-10                       |
| Author(s)            | Prepared by LS-DYNA® Aerospace Working Group        |
| Number of pages      | 18                                                  |
| Date created         | Wednesday 12 <sup>th</sup> July, 2017               |
| Distribution         | LS-DYNA® Aerospace Working Group / internal LSTC QA |

# Contents

|          |                                                |           |
|----------|------------------------------------------------|-----------|
| <b>1</b> | <b>Introduction</b>                            | <b>1</b>  |
| 1.1      | Purpose of this Document . . . . .             | 1         |
| <b>2</b> | <b>Test Case Information</b>                   | <b>2</b>  |
| <b>3</b> | <b>Test Case Specification</b>                 | <b>3</b>  |
| 3.1      | Test Case Purpose . . . . .                    | 3         |
| 3.2      | Test Case Description . . . . .                | 4         |
| 3.3      | Model Description . . . . .                    | 5         |
| <b>4</b> | <b>Test Specifications</b>                     | <b>7</b>  |
| 4.1      | Test Case Targets . . . . .                    | 7         |
| 4.2      | Pass/Fail Criteria . . . . .                   | 8         |
| <b>5</b> | <b>Test Case Results</b>                       | <b>9</b>  |
| 5.1      | Software and Hardware Specifications . . . . . | 9         |
| 5.2      | Results Summary . . . . .                      | 10        |
| 5.3      | Result Details . . . . .                       | 11        |
| 5.3.1    | Sub Test Case ID 1 - Test Target 1 . . . . .   | 12        |
| 5.3.2    | Sub Test Case ID 1 - Test Target 2 . . . . .   | 13        |
| 5.3.3    | Sub Test Case ID 1 - Test Target 3 . . . . .   | 14        |
| 5.3.4    | Sub Test Case ID 1 - Test Target 4 . . . . .   | 15        |
| 5.3.5    | Sub Test Case ID 1 - Test Target 5 . . . . .   | 16        |
| 5.3.6    | Sub Test Case ID 1 - Test Target 6 . . . . .   | 17        |
|          | <b>References</b>                              | <b>18</b> |

# **1 Introduction**

## **1.1 Purpose of this Document**

This document specifies the test case AWG-ERIF-7. It provides general test case information like name and ID as well as information to the confidentiality, status, and classification of the test case.

A detailed description of the test case is given, the purpose of the test case is defined, and the tested features are named. The test case specifications also state the target measures for testing and the expected results, as well as their pass and fail criteria.

Testing results are provided in section 5 for the therein mentioned LS-DYNA® version and platforms.

## 2 Test Case Information

| Test Case Summary        |                                                                                                                  |
|--------------------------|------------------------------------------------------------------------------------------------------------------|
| Confidentiality          | external use                                                                                                     |
| Test Case Name           | Ballistic Impact on Composite Plate                                                                              |
| Test Case ID             | AWG-ERIF-7                                                                                                       |
| Test Case Status         | active                                                                                                           |
| Test Case Classification | Validation                                                                                                       |
| Test Case Source         | Boeing<br>UC Berkeley - Mechanical Engineering Department                                                        |
| Tested Keyword           | *MAT_COMPOSITE_DMG_MSC,<br>*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_TIEBREAK,<br>*CONTACT_ERODING_SINGLE_SURFACE_ID |
| Member of Test Suite     | AWG ERIF SUITE                                                                                                   |
| Metadata                 | AWG ERIF                                                                                                         |

Table 1: Test Case Summary

## **3 Test Case Specification**

### **3.1 Test Case Purpose**

The purpose of Test Case ID AWG-ERIF-7 is the validation of a steel projectile impact on a 16 ply composite plate. The reliability and consistency of LS-DYNA® as a finite element solver for this impact simulation involving composite structures is evaluated by performing analyses on different cpu architecture platforms and comparison to experimental results.

### 3.2 Test Case Description

This Test Case contains an impact analysis (see figure 1) with a steel cylinder projectile impacting a 16 ply carbon fiber composite plate. Details on the experimental set up and experimental results can be found in [2].

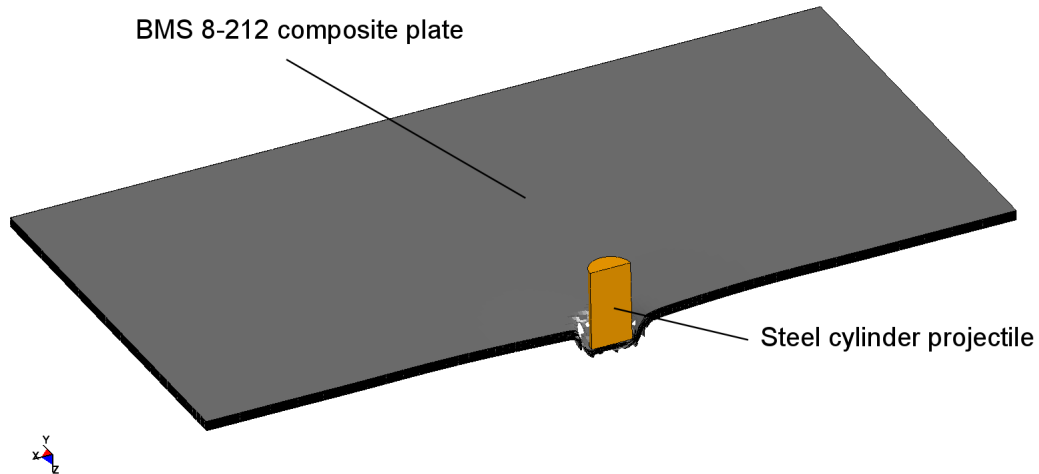


Figure 1: Model sketch: Tool steel cylinder projectile impacting 16 ply BMS 8-212 composite plate

Table 2 contains a short summary of the physical model set up.

| Physical Model Information  |                                              |
|-----------------------------|----------------------------------------------|
| projectile geometry         | length = 2.0" , diameter = 0.5"              |
| projectile mass             | 0.082 lb                                     |
| projectile material         | tool steel                                   |
| projectile initial velocity | 4758 in/s                                    |
| projectile final velocity   | 4133 in/s                                    |
| plate geometry              | 12.0" x 12.0" (clamp frame inside 10" x 10") |
| plate material              | BMS 8-212                                    |
| plate material density      | 0.056 lb per cubic inch                      |
| ply orientation             | [0/45/90/-45] <sub>4s</sub>                  |

Table 2: Model set-up data



### 3.3 Model Description

The model geometry is discretized with solid elements for the projectile and for each single ply of the 16 ply composite (see figure 2). Due to symmetry conditions, a half model of the actual geometry is used. Symmetry boundary conditions are applied on the symmetry plane and the outer edges of the composite plate are fully supported. The projectile has an initial z velocity defined on all nodes and is guided along the symmetry plane. The number of elements and material specifications for the model can be found in table 3 and table 4 reflects the sub test case specification.

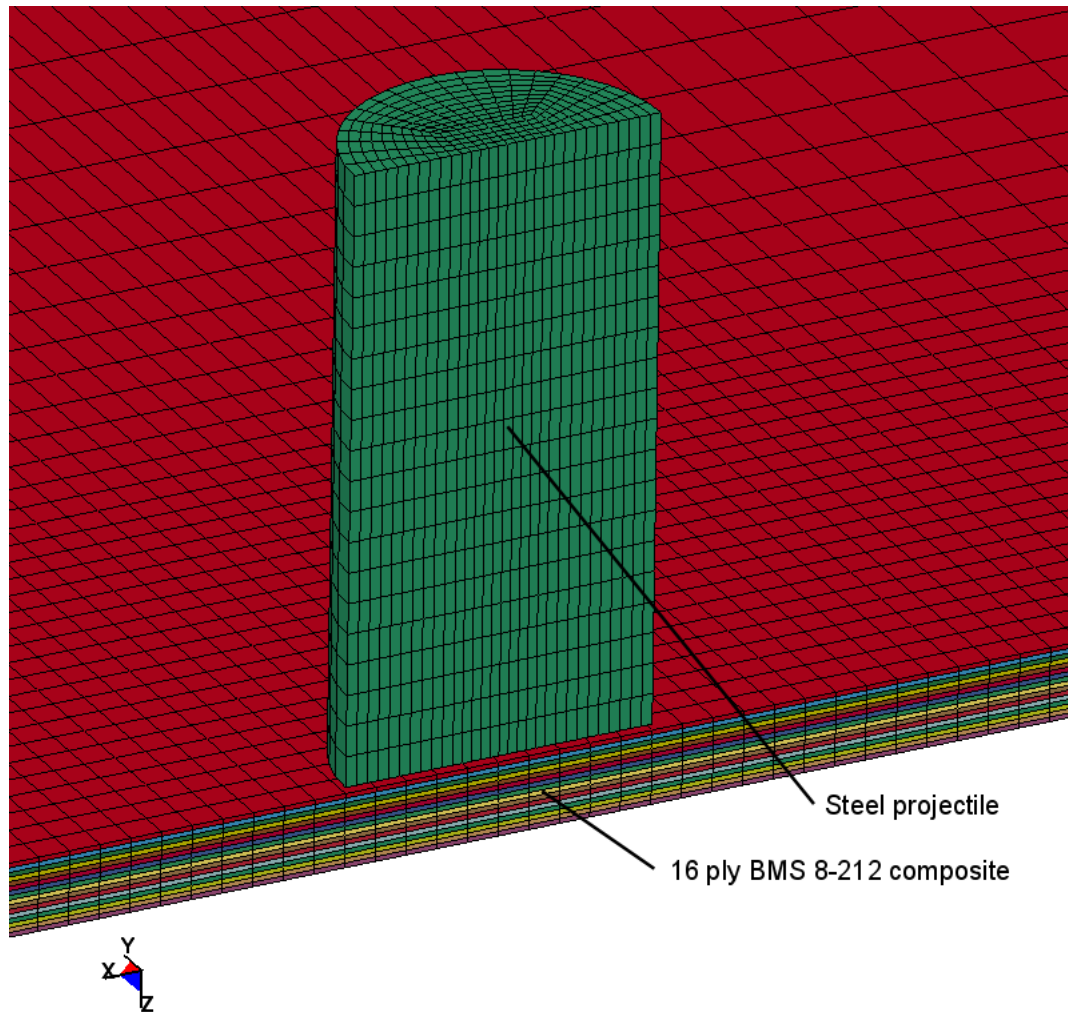


Figure 2: FEA model: Tool steel cylinder projectile impacting 16 ply BMS 8-212 composite plate

The material definitions and their parameters can be found in the input decks.

| FEA Model information       |                                                                                     |
|-----------------------------|-------------------------------------------------------------------------------------|
| Nodes                       | 122756                                                                              |
| Solid elements              | 61488                                                                               |
| Solid materials             | 17                                                                                  |
| Parts                       | 17                                                                                  |
| projectile geometry         | length = 1.0" , diameter = 0.5"                                                     |
| projectile mass             | 0.712E-04 lbf-s <sup>2</sup> /in                                                    |
| projectile material         | *MAT_PLASTIC_KINEMATIC                                                              |
| projectile initial velocity | 4758 in/s                                                                           |
| plate geometry              | 10.0" x 10.0" x 0.12"                                                               |
| plate material              | *MAT_COMPOSITE_DMG_MSC                                                              |
| Units                       | in (length), s (time), lbf-s <sup>2</sup> /in (mass), psi (stress), lbf-in (energy) |

Table 3: FEA Model Information

| Sub Test Case ID | Input Deck Name                                      |
|------------------|------------------------------------------------------|
| 1                | aerospace_group_example_07_impact_16_ply_composite.k |

Table 4: Specification of sub test cases

## 4 Test Specifications

### 4.1 Test Case Targets

Table 5 displays the test case targets. The test case targets specify values or a series of values taken from the finite element analysis solution of the test case and they are used in a comparison of analysis results and experimental data. They are chosen in a way that they can be directly or indirectly compared to the experimentally determined values or observations.

| Test Case Targets |                  |                |                  |                    |
|-------------------|------------------|----------------|------------------|--------------------|
| Target number     | output           | component type | component id     | retrieved from     |
| 1                 | internal energy  | global         | -                | binout/glstat file |
| 2                 | kinetic energy   | global         | -                | binout/glstat file |
| 3                 | hourglass energy | global         | -                | binout/glstat file |
| 4                 | internal energy  | part           | 100 (projectile) | binout/matsum file |
| 5                 | kinetic energy   | part           | 100 (projectile) | binout/matsum file |
| 6                 | z-velocity       | part           | 100 (projectile) | binout/matsum file |

Table 5: Test Case targets for Test Case ID AWG-ERIF-7

Test case targets one to five are used to evaluate the cross cpu architecture consistency whereas test case target six is used to compare the analysis with the experimental data (see section 4.2).

## 4.2 Pass/Fail Criteria

These are the Pass/Fail criteria used for the cross cpu architecture consistency and the Validation of the Test Case ID AWG-ERIF-7.

The sub test case passes if the test case target data falls within the corridor bounds. Otherwise the test fails.

The test case corridors are upper and lower bounds for the test case targets. They were defined based on the test target data obtained with LS-DYNA® R9.0 Revision 108899 binaries by the following process:

- For a specific test case target, interpolate the data from different platform and executable (R9.0 Revision 108899) combinations, so that the time domain is the same.
- Calculate the upper and lower bounds of the test case targets 1-2, and 4-6 by:

$$bound_{up}(i) = max(i) + 0.2 \times [max(i) - min(i)] + 0.05 \times peak$$

$$bound_{low}(i) = min(i) - 0.2 \times [max(i) - min(i)] - 0.05 \times peak$$

Calculate the upper and lower bounds of the test case target 3 (glstat: hourglass energy) by:

$$bound_{up}(i) = max(i) + 0.2 \times [max(i) - min(i)] + 0.05 \times peak$$

$$bound_{low}(i) = min(i) - 0.05 \times peak$$

where  $max(i)$ ,  $min(i)$  are the maximum and minimum values at the  $i_{th}$  time step across all platforms and executable (R9.0 Revision 108899) combinations the test case was calculated with,  $peak$  is the maximum absolute y value across the whole time domain,  $bound_{up}(i)$  and  $bound_{low}(i)$  are the upper and lower bounds for the  $i_{th}$  time step.

Note: for the test case target 2 (glstat: kinetic energy), the results obtained on the platform ham with R9.0 Revision 108899 significantly deviated from those obtained on other platforms (sandwich and sgi64e), thus the results from ham were removed from calculating the upper and lower bounds.

## 5 Test Case Results

### 5.1 Software and Hardware Specifications

In order to ensure cross-platform consistency, the herein mentioned sub test cases are run on platforms specified in table 6 and the results are calculated with software versions defined in table 7.

| Platform Name | Operating system | CPU type                        | MPI-Protocol         | Number of cpu's <sup>1</sup> |
|---------------|------------------|---------------------------------|----------------------|------------------------------|
| mars          | CentOS 6.5       | Intel® Xeon® E5- 2640 @ 2.50GHz | Platform MPI 8.2.0.0 | 4                            |
| dinar3b       | SUSE LES 11      | AMD® Opteron ® 6276 @ 2300MHz   | Platform MPI 8.2.0.0 | 4                            |

<sup>1</sup> Number of cpu's used for calculation of the test case

Table 6: Used Platforms and CPU Type's

| Product  | Version | Release | Revision | Parallel type <sup>1</sup> | Precision <sup>2</sup> | executable       |
|----------|---------|---------|----------|----------------------------|------------------------|------------------|
| LS-DYNA® | 971     | R9      | 118235   | SMP                        | SP                     | ls971.118235.R9  |
| LS-DYNA® | 971     | R9      | 118235   | SMP                        | DP                     | ld971.118235.R9  |
| LS-DYNA® | 971     | R9      | 118235   | MPP                        | SP                     | mpp971.118235.R9 |
| LS-DYNA® | 971     | R9      | 118235   | MPP                        | DP                     | mpd971.118235.R9 |

<sup>1</sup> MPP = Massively Parallel Processing, SMP = Symmetric Multiprocessing

<sup>2</sup> SP = single precision, DP = double precision

Table 7: Tested LS-DYNA® version

## 5.2 Results Summary

Table 8 contains the results of the Test Case ID AWG-ERIF-7 completed with all combinations of software and hardware defined in section 5.1 (1 \* 2 \* 4 total calculation runs).

Details on the test results can be found in the section 5.3.

The table 8 cross cpu architecture consistency and validation summary is:

- **PASS** - Pass criteria in section 4.2 is attained.
- **FAILED** - Pass criteria in section 4.2 is not attained.
- **ERROR** - sub test case terminates due to error.
- **N/A** - sub test case was not calculated.

| Sub Test Case ID | PASS/FAILED |
|------------------|-------------|
| 1                | <b>PASS</b> |

Table 8: Validation results summary for Test Case ID AWG-ERIF-7

### 5.3 Result Details

The following subsections contain detailed results for the Test Case ID AWG-ERIF-7 for LS-DYNA® R9 Revision 118235.

For each sub test case defined in section 3.3 there is a graph displaying the time history of the result target defined in section 4.1 for the platform and software version combinations defined in section 5.1.

The title of the graph states the test case ID and the name of input deck. The legend contains the result file name, output, platform, executable and number of cpu's separated by comma. A minus sign before the number of cpu's refers to the compatibility option for SMP calculations (see [1] for details on this option).

#### Example for title and legend:

*Title:*

'AWG\_ERIF\_TEST\_CASE\_7: aerospace\_group\_example\_07\_impact\_16\_ply\_composite.k' states the test case ID 7 and name of the input deck for sub test case 1.

*Legend:*

'glstat\_internal\_energy,ham,ls971.118235.R9,4' states that the graph shows the internal energy derived from the 'glstat' output file for an input deck which was calculated on the 'ham' platform with a LS-DYNA® R9 Revision 118235 binary (SMP, single precision) on four processors.

### 5.3.1 Sub Test Case ID 1 - Test Target 1

AWG\_ERIF\_TEST\_CASE\_7: aerospace\_group\_example\_07\_impact\_16\_ply\_composite.l

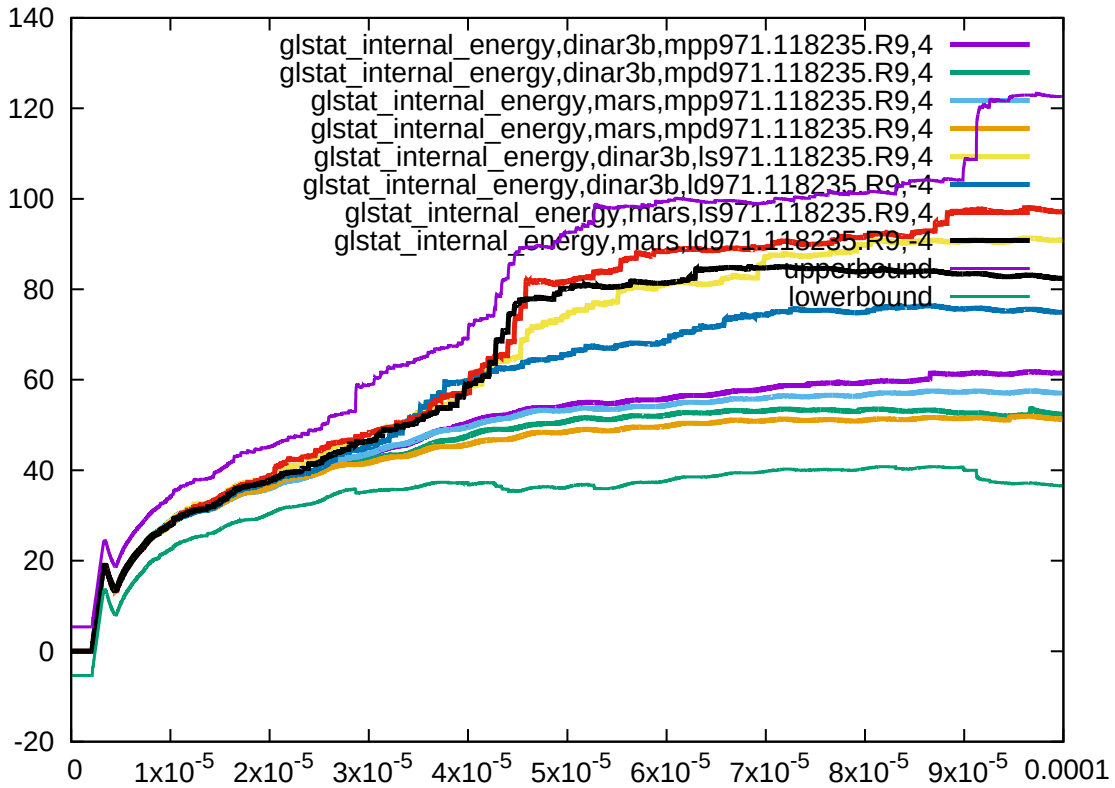


Figure 3: Cross platform results, global internal energy, sub test case ID 1



### 5.3.2 Sub Test Case ID 1 - Test Target 2

AWG\_ERIF\_TEST\_CASE\_7: aerospace\_group\_example\_07\_impact\_16\_ply\_composite.l

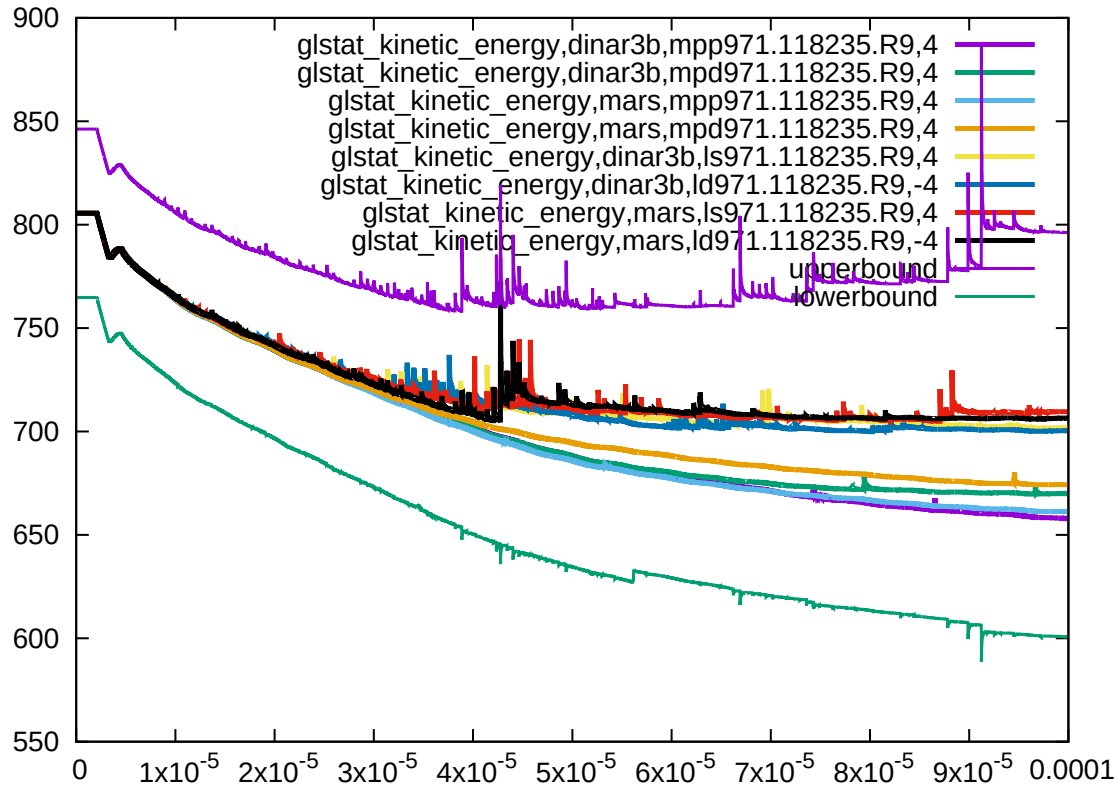


Figure 4: Cross platform results, global kinetic energy, sub test case ID 1

### 5.3.3 Sub Test Case ID 1 - Test Target 3

AWG\_ERIF\_TEST\_CASE\_7: aerospace\_group\_example\_07\_impact\_16\_ply\_composite.l

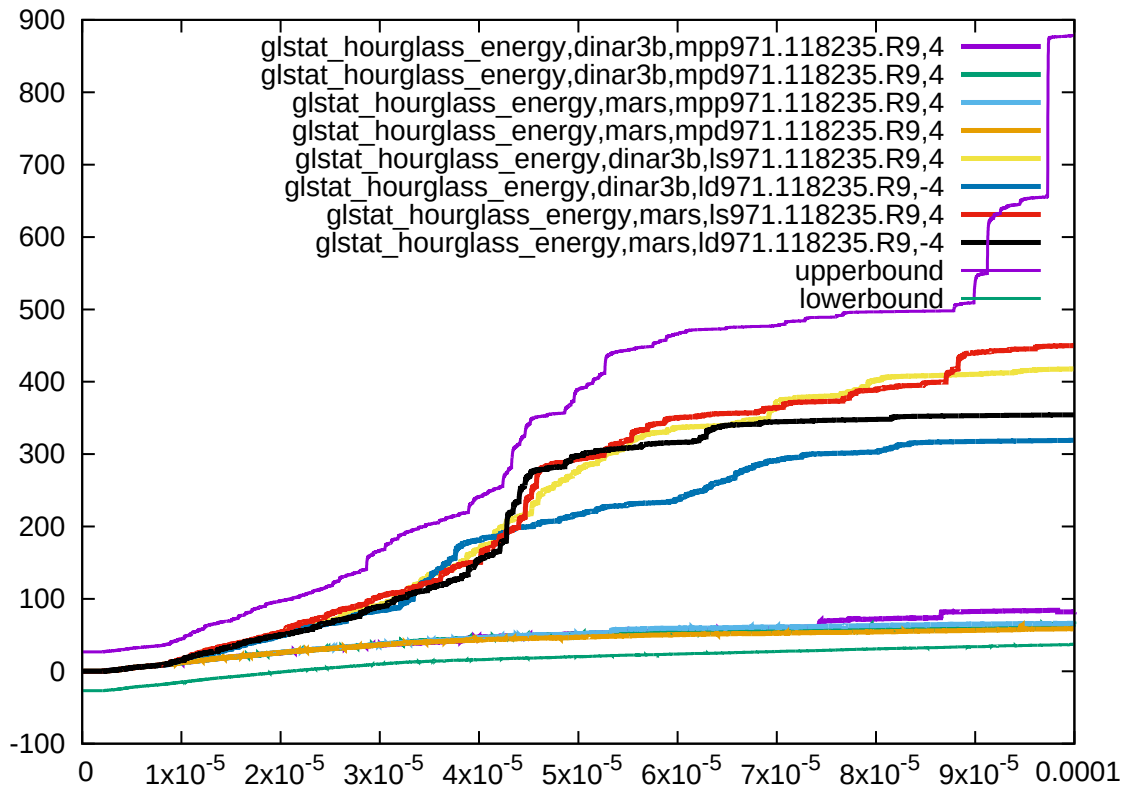


Figure 5: Cross platform results, global hourglass energy, sub test case ID 1

### 5.3.4 Sub Test Case ID 1 - Test Target 4

AWG\_ERIF\_TEST\_CASE\_7: aerospace\_group\_example\_07\_impact\_16\_ply\_composite.k

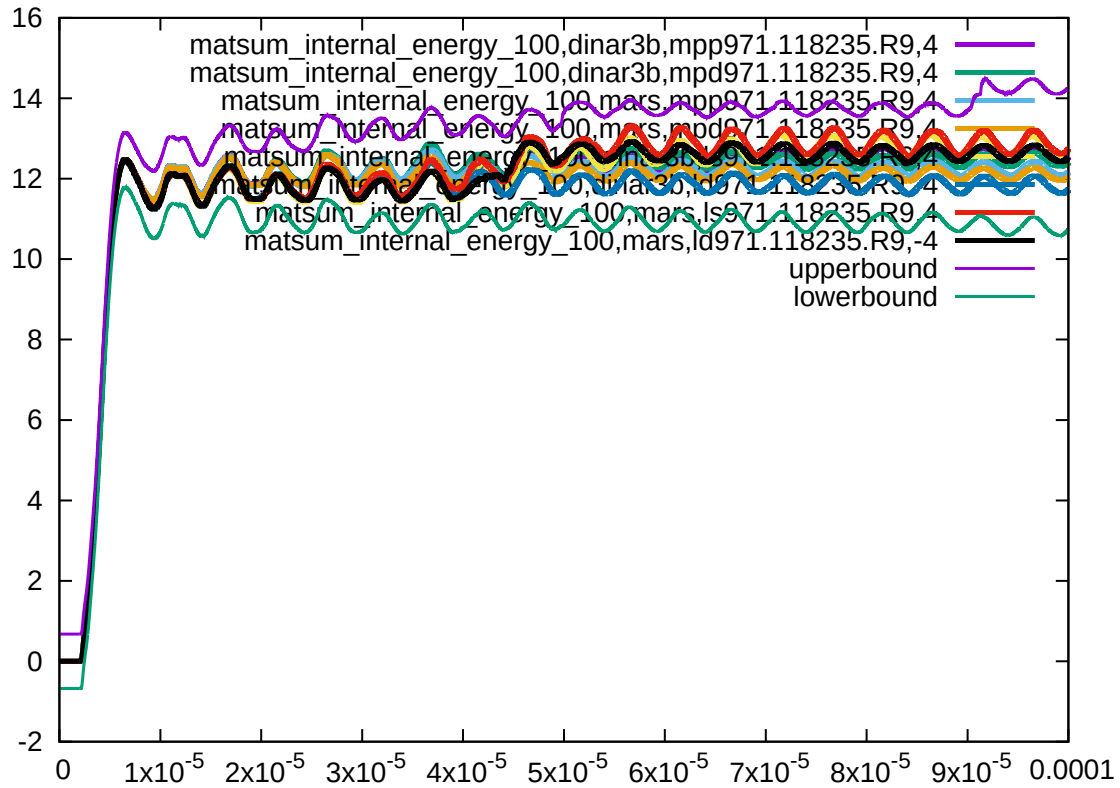


Figure 6: Cross platform results, internal energy part 100, sub test case ID 1

### 5.3.5 Sub Test Case ID 1 - Test Target 5

AWG\_ERIF\_TEST\_CASE\_7: aerospace\_group\_example\_07\_impact\_16\_ply\_composite.l

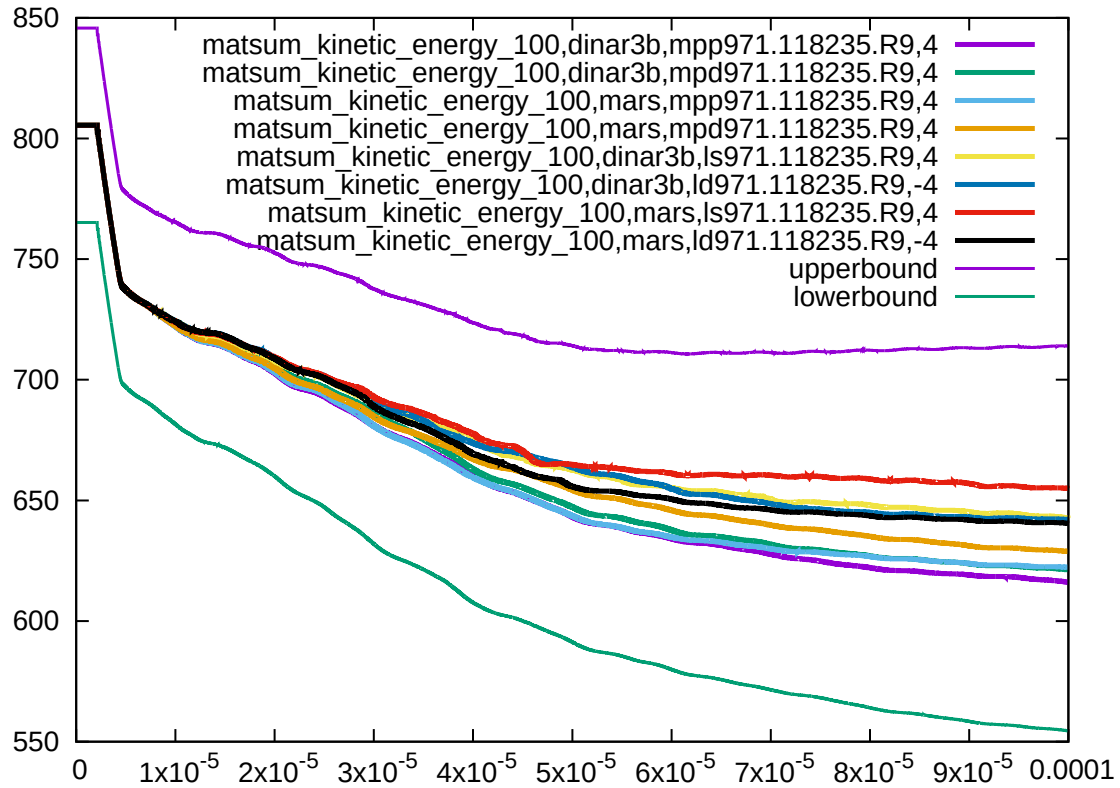


Figure 7: Cross platform results, kinetic energy part 100, sub test case ID 1

### 5.3.6 Sub Test Case ID 1 - Test Target 6

AWG\_ERIF\_TEST\_CASE\_7: aerospace\_group\_example\_07\_impact\_16\_ply\_composite.

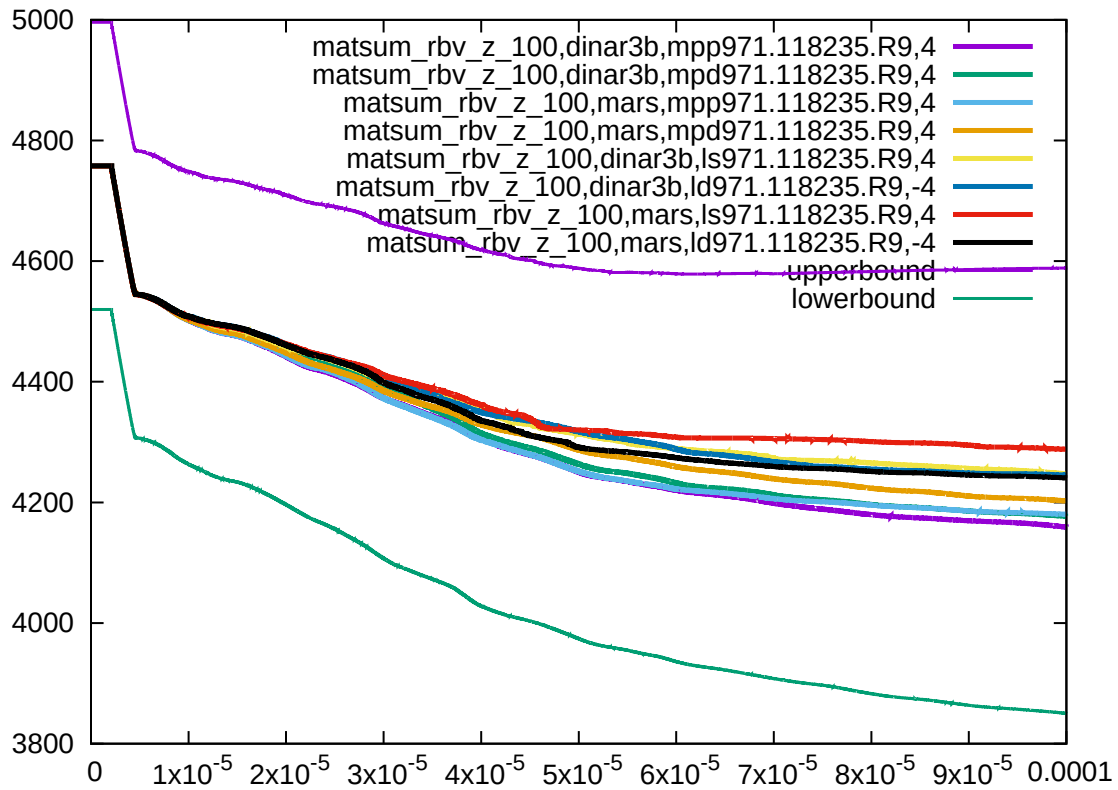


Figure 8: Cross platform results, z-velocity part 100, sub test case ID 1

## References

- [1] LSTC, *LS-DYNA KEYWORD USER MANUAL*, 7374 Las Positas Road, Livermore, CA, 94551, USA, version 971 ed., May 2007.
- [2] D. POWELL, T. ZOHDI, AND G. JOHNSON, *Impact and Delamination Failure Characterization of BMS 8-212 Air Traffic Organization*, Final Report DOT/FAA/AR-08/48, U.S. Department of Transportation, Federal Aviation Administration, Office of Aviation Research, Washington, D.C. 20591, October 2008.